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Determination in broilers and turkeys of true phosphorus digestibility and retention in wheat distillers dried grains with solubles without or with phytase supplementation

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ABSTRACT

Wheat distillers dried grains with solubles (**wheat-DDGS**) is a viable source of P for poultry. Two experiments were conducted to determine the true ileal P digestibility (**TPD**) and true total tract P retention (**TPR**) of wheat-DDGS without or with phytase supplementation for broilers and turkeys. In experiment 1 (broilers), wheat-DDGS inclusion linearly decreased ($P < 0.05$) dietary ileal DM digestibility and total tract DM and P retention. The coefficient of TPD without or with phytase for broilers was 0.94 or 0.96, respectively. The coefficient of TPR was 0.92 and 0.94 without or with phytase, respectively. In experiment 2 (turkeys), wheat-DDGS inclusion linearly decreased ($P < 0.05$) dietary ileal DM digestibility and total tract DM retention. The coefficient of TPD of wheat-DDGS for turkeys was 0.76 or 0.82 without or with phytase, respectively. The coefficient of TPR of wheat-DDGS without or with phytase was 0.71 and 0.82, respectively. Phytase had no effect ($P > 0.05$) on dietary ileal DM digestibility, total tract DM retention, ileal P digestibility and total tract P retention for broilers and turkeys. Phytase had no effect ($P > 0.05$) on TPD and TPR for broilers and turkeys. It was concluded that wheat-DDGS is a valuable dietary source of digestible P for broilers and turkeys.

Keywords: broilers, phosphorus digestibility and retention, phytase, turkeys, wheat-DDGS

1. Introduction

Wheat distillers dried grains with solubles (**wheat-DDGS**) is the co-product of bioethanol produced from wheat grain by the dry-grind process. It is possible to use wheat-DDGS as a source of metabolisable energy and amino acids (**AA**) for broilers and turkeys (Bandegan et al., 2009; Bolarinwa and Adeola, 2012), but the value of wheat-DDGS as a source of P for poultry

has not been investigated. Wheat-DDGS has the potential to be a good source of digestible P for poultry because substantial concentrations of phytate P are hydrolysed by the action of yeast phytase during the fermentation process in bioethanol production (Liu, 2011).

The use of exogenous phytase in poultry diets is not new and a plethora of studies have documented the efficacy of exogenous phytase in releasing phytate P and improving P digestibility for poultry. Martinez-Amezcua et al. (2004) noted that up to 25% of the total P in maize-DDGS may be bound to phytate. As such, there is an opportunity to improve P digestibility in wheat-DDGS for broilers and turkeys using exogenous phytase. Few studies have determined the value of exogenous phytase in diets containing maize-DDGS for broilers (Martinez-Amezcua et al., 2006; Olukosi et al., 2010).

Broiler and turkey diets are formulated to contain optimal levels of P that best supports maintenance and performance. It is essential to provide information about the digestible P content of wheat-DDGS, because digestible P values of feed ingredients are a more accurate measure of bird requirement compared with total P values. WPSA (2013) developed a standard protocol for determining digestible P in feed ingredients for broilers and encourages using digestible P as a measure of bird P requirements.

The objective of the current study was to determine the true ileal P digestibility (**TPD**) and true total tract P retention (**TPR**) of wheat-DDGS without or with phytase supplementation in broilers and turkeys.

2. Materials and methods

2.1. Animals and management

The Scotland's Rural College Animal Experiment Committee approved all bird handling and sample collection procedures.

On hundred and twenty-six Ross 308 male broiler chicks (Experiment 1) or 126 BUT 10 male turkey poults (Experiment 2) were used for determination of TPD and TPR of wheat-DDGS. Birds had *ad libitum* access to the diets and water in the entire pre- and experimental periods. The birds were reared in a house with facilities to control temperature, light, and humidity. In the two experiments, the birds were offered a pre-experimental diet that offers energy and nutrients comparable with specific breed requirements. In each experiment, birds were allocated to one of 6 experimental diets in a randomised complete block design using d 14 bodyweight as blocking criterion and transferred to metabolism cages on d 14. Each treatment had seven replicate cages and three birds per replicate cage.

2.2. Diets and sample collection

The pre-experimental diet offered from d 1 to 14 in experiment 1 and 2 contained (as-is) 12.7 MJ/kg of ME, 230 g/kg of CP and 6.8 g/kg of P. The 6 experimental diets used in each experiment consisted of three levels of wheat-DDGS in a maizestarch-dextrose based diet (200, 400 or 600 g/kg) and two levels of phytase (without or with) in a 3 × 2 factorial arrangement. The phytase was added at a rate of 1000 FTU/kg. The phytase was derived from *Escherichia coli* and expressed in *Schizosaccharomyces pombe*. One phytase unit was defined as the quantity of enzyme required to liberate 1 µmol of inorganic P per min, at pH 5.5 from an excess of 15 µM sodium phytate at 37^{o}C.

Titanium dioxide was added to the experimental diets (3 g/kg of diet) to enable determination of ileal P digestibility or total tract P retention by the index method. Experimental diets were offered between d 14 and 21. The ingredient and chemical compositions of the experimental diets used in both experiments are shown in Table 1. Excreta were collected daily from each cage for 3 d (d 18 to 20), dried and pooled within a cage. Birds were euthanized by cervical dislocation on d 21 and ileal digesta were collected from the Meckel's diverticulum to approximately 1 cm proximal to the ileo-cecal junction by flushing with distilled water. Ileal digesta were pooled within a cage and subsampled for analyses. Samples of diets, wheat-DDGS, excreta and ileal digesta were oven dried and ground to 0.5 mm particle size using a mill grinder (Retsch ZM 100, F. Kurt Retsch GmbH & Co.KG, Haan, Germany) before chemical analysis. Samples of diets, wheat-DDGS, ileal digesta and excreta were analyzed for P, DM and Ti.

2.3. Chemical analysis

To determine DM, samples were dried at 105 ^{o}C for 24 hours (method 930.15; AOAC, 2006) in a drying oven (Uniterm, Russel-Lindsey Engineering Ltd., Birmingham, England. UK). Ash content was determined by heating wheat-DDGS samples in a muffle furnace at 500°C for 24 hours (Method 934.01; AOAC, 2006). Ether extract was determined using AOAC Method 920.39 (AOAC, 2003). Gross energy was determined in a Parr adiabatic bomb calorimeter using benzoic acid as an internal standard (Model 6200, Parr Instruments, Moline, Illinois, USA). Nitrogen was determined by the combustion method (method 968.06; AOAC 2006). For AA analyses, samples were hydrolyzed for 24 hours in 6 *N* hydrochloric acid at 110^{o}C under an atmosphere of N. For Met and Cys, performic acid oxidation was carried out before acid hydrolysis. The AA in the hydrolysate were determined by High Performance Liquid

Chromatography after post-column derivatization [(method 982.30E (a, b, c); AOAC 2000]. Analysis for Ti was done as described by Short et al. (1996). Mineral concentrations in the samples were determined using inductively coupled plasma spectrophotometry following the procedures of Olsen and Sommers (1982). Crude fiber, NDF and ADF in the diets were determined using the ANKOM's proprietary 200 Filter Bag Technique in Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Phytate P in wheat-DDGS was determined using inductively coupled plasma atomic emission spectroscopy (method 925.10; AOAC, 1990). Phytase activity in diets was determined using AOAC method 2000.12 (AOAC, 2000).

2.4. Calculations and statistical analysis

Dietary ileal P digestibility or total tract P retention was calculated using the index method. True ileal P digestibility or TPR was determined from the regression of P output at the ileal or total tract against dietary P intake as done by Dilger and Adeola (2010). The regression model was:

1. $\text{PO-dmi} = (\text{TPI} \times \text{Pi}) + \text{EPL}$

where PO-dmi is P output (g/kg of DM intake); TPI is true P indigestibility; P_i is P intake (g/kg DM) and EPL is endogenous P loss (g/kg of DM intake).

The coefficient of TPD or TPR was calculated from the measure of P indigestibility using the following equation:

2. $\text{TPD or TPR} = 1 - \text{TPI}$

where TPD is coefficient of true ileal P digestibility, TPR is coefficient of true total tract P retention and TPI is true P indigestibility, respectively.

Digestible phosphorus (DP) and retainable phosphorus (RP) contents in the wheat-DDGS were calculated using the following equation:

3. $$\text{DP or RP}\left({}^{\text{g}}/_{\text{kg}}\,\text{DM}\right) = [(\text{TPD or TPR}) \times \text{DDGS} - \text{P}]$$

where TPD is coefficient of true ileal P digestibility, TPR is coefficient of true total tract P retention and DDGS-P is analyzed P content (g/kg) in the wheat-DDGS.

Data were analyzed using the Generalized Linear Mixed Models of Genstat Statistical Package (11th edition, VSN International). Statistical significance was set at $P < 0.05$ for all mean comparisons. Dietary DM and P ileal digestibility and total tract retention data were analyzed as a 3 × 2 factorial of wheat-DDGS inclusion level (200, 400 or 600 g/kg) and phytase (without or with) using ANOVA procedures. Orthogonal contrasts were used to determine the effects of graded wheat-DDGS intake and phytase supplementation on apparent P digestibility and retention. The regression of P output against P intake was done using regression analysis procedures. Improvements due to phytase supplementation were determined using ANOVA procedures as the difference between the slopes of treatments not supplemented with phytase and those supplemented with phytase.

3. Results

The chemical composition of the wheat-DDGS used in the current study is presented in Table 2. The total P, crude fibre, CP and AA contents in the wheat-DDGS were greater compared with wheat.

Ileal digestibility and total tract retention of DM and P for broilers and turkeys offered graded levels of wheat-DDGS without- or with supplemental phytase are presented in Table 3. There was no wheat-DDGS × phytase interaction ($P > 0.05$) for dietary ileal DM digestibility, total tract DM retention, ileal P digestibility and total tract P retention for broilers and turkeys. In broilers, increasing the inclusion level of wheat-DDGS in the diet linearly decreased ($P < 0.05$) ileal DM digestibility and total tract DM retention and apparent total tract P retention but had no effect ($P > 0.05$) on apparent ileal P digestibility. In turkeys, increasing the inclusion level of wheat-DDGS in the diet linearly decreased ($P < 0.05$) ileal DM digestibility and total tract DM retention but had no effect ($P > 0.05$) on either apparent ileal P digestibility or apparent total tract P retention.

True P ileal digestibility and TPR in wheat-DDGS without or with supplemental phytase for broilers is presented in Table 4. In broilers, the coefficient of TPD of wheat-DDGS without or with supplemental phytase was 0.94 or 0.96, respectively. Corresponding coefficients of TPR were 0.92 and 0.94, respectively. Phytase supplementation had no effect ($P > 0.05$) on TPD or TPR in broilers. The digestible P and retainable P (DP and RP, respectively) contents in the wheat-DDGS were calculated as the coefficient of TPD or TPR multiplied by the analyzed P content (g/kg) in the wheat-DDGS. The DP content (g/kg) in the wheat-DDGS for broilers without or with phytase was 6.0 or 6.2, respectively whereas RP content (g/kg) was 6.0 or 6.1, respectively. The intercept in the regression equations in Table 4 represents endogenous P losses

at the ileal and total tract. Ileal endogenous P loss (mg/kg of DMI) without or with phytase were 476 or 174, respectively. Endogenous P losses (mg/kg of DMI) at the total tract without or with phytase were 625 or 201, respectively.

True P ileal digestibility and TPR in wheat-DDGS without or with supplemental phytase for turkeys is presented in Table 4. In turkeys, the coefficient of TPD in wheat-DDGS without or with phytase supplementation was 0.76 and 0.82, respectively. Corresponding coefficients of TPR in the wheat-DDGS was 0.71 and 0.82, respectively. Phytase supplementation had no effect ($P > 0.05$) on TPD or TPR in the wheat-DDGS for turkeys. Digestible P content (g/kg) in the wheat-DDGS without or with phytase for turkeys was 4.9 or 5.3, respectively whereas RP (g/kg) content was 4.6 or 5.3, respectively. Endogenous P losses at the ileal or total tract without or with phytase are presented in Table 4. Ileal endogenous P loss (mg/kg of DMI) without or with phytase were 430 or 98, respectively. Endogenous P losses (mg/kg of DMI) at the total tract without or with phytase were 293 or 451, respectively.

4. Discussion

The objective of the current study was to determine the TPD and TPR of wheat-DDGS without or with phytase supplementation for broilers and turkeys. Determination of TPD and TPD in feedstuffs for broilers and turkeys is important because excessive P in poultry manure is potentially harmful to the environment. The concentration of P is increased three-fold in DDGS after the removal of starch in the grain during bioethanol production (Thacker and Widyaratne, 2007). Of greater importance is a large proportion of phytate-bound P in the grain is hydrolysed by the actions of yeast phytase during fermentation, therefore increasing the concentrations of non phytate P in DDGS (Liu, 2011). Because phytate-P is poorly utilised by poultry, feedstuffs

containing low levels of phytate P are often desirable. However, it is unlikely that yeast phytase will exert a complete hydrolyses of phytate-P during the fermentation process. Martinez-Amezcua et al., 2004) observed that up to 25% of the total P in maize-DDGS was phytate-bound. Therefore, there is a chance to improve P digestibility in wheat-DDGS for broilers and turkeys using exogenous phytase.

The wheat-DDGS used in the current study contained 7.6 g/kg DM of total P which is lower compared with the 12.3 g/kg DM reported by Thacker and Widyaratne (2007) or the 9.4 g/kg DM noted by Nyachoti et al. (2005). Olukosi and Adebiyi (2013) observed that P content in eleven samples of wheat-DDGS from published data and from different sources ranged from 6.5 to 11.1 g/kg and concluded that P content in wheat-DDGS from different sources is markedly variable. The differences in P content of wheat-DDGS are likely due to differences in the P composition in the wheat used or to differences in processing techniques.

Increasing the inclusion level of wheat-DDGS reduced dietary DM digestibility and total tract DM retention for broilers and turkeys in the current study. Increased levels of dietary fibre decreases DM and nutrient digestibility in broilers (Jørgensen et al., 1996). Increasing wheat-DDGS inclusion levels in a wheat-SBM based diet reduced DM and energy retention in broilers (Bolarinwa and Adeola, 2012). Thacker and Widyaratne (2007) reported a reduction in apparent P retention when using graded levels of wheat-DDGS in a practical wheat-SBM diet for broilers. The increase in dietary fibre as wheat-DDGS replaced maize-starch in the diets may explain the reduction in DM digestibility and retention observed in the current study.

Phytase had no effect on dietary P digestibility and retention for broilers and turkeys in the current study. The efficacy of supplemental phytase to release P bound to phytate for poultry and

pig have been described extensively in the literature and reviewed (Selle and Ravindran, 2007; Woyengo and Nyachoti, 2011). The lack of improvement in dietary P digestibility and retention as observed in the current study may be due to the characteristics of the wheat-DDGS. Liu and Han (2011) assessed the concentrations of different forms of P (non phytate-P, phytate-bound P, and total P) in different streams of the bioethanol production process and reported an increase in maize-DDGS over maize grain of 1.8 fold in phytate-P and 10.8 fold in non-phytate P. Liu and Han (2011) observed that during the fermentation process, percentage phytate-P in total P decreased significantly whereas percentage non phytate-P in total P increased. These observations implied that phytate underwent degradation through the actions of yeast phytase. In addition, Martinez-Amezcua et al. (2004) observed that the hydrolysis of phytate in the DDGS during fermentation is often incomplete, and that heat treatment during the drying step may further dissociate P from phytate in DDGS.

It is possible to extrapolate the TPD or TPR and basal endogenous P loss from the linear relationship between undigested P and dietary P intake using the regression method. In the current study, there was a strong relationship between undigested P and dietary P intake, which is important when using the regression method. The regression method has been used to determine TPD and TPR of feedstuffs for broilers (Dilger and Adeola, 2006) and swine (Akinmusire and Adeola, 2009).

Mutucumarana et al. (2014) reported the coefficient of TPD in corn-DDGS to be 0.727, a value that is lower compared with the 0.94 or 0.96 for the coefficient of TPD in broilers without or with phytase, respectively noted in the current study. It is expected that differences in the grain used, processing techniques and DDGS chemical characteristics will affect TPD in DDGS

for broilers and may explain the differences in TPD noted in the current study and that of Mutucumarana et al. (2004). The ileal digestible P or total tract retainable P contents in wheat-DDGS were greater for broilers compared with turkeys in the current study. The difference in TPD and TPR between broilers and turkeys in the current study is probably due to differences in physiological maturity between the two species at 21 d of age. Uni et al. (1995; 1999) reported that post hatch development of the small intestine in turkeys is slower compared with that of the broiler chick. It is speculated that broilers being physiological more mature on day 28 were able to utilise AA in the wheat-DDGS more efficiently compared with turkeys at the same age.

Endogenous P losses ranged from 98 to 625 mg/kg of DMI in the current study. Mean ileal endogenous P losses in broilers were reported to be 272 mg/kg of DMI (Rutherfurd et al., 2002) or 446 (Rutherfurd et al., 2004) or 418 mg/kg of DMI (Mutucumarana et al., 2014). The endogenous P losses of 272 or 446 mg/kg of DMI noted by Rutherfurd et al. (2002; 2004) and 418 mg/kg of DMI noted by Mutucumarana et al. (2014) falls within the range of endogenous P losses at the ileal noted in the current study for broilers. Modest differences in endogenous P losses may be expected among studies due to differences in the chemical characteristics of the feed ingredients or diets used.

Supplemental phytase had no effect on ileal or total tract endogenous P losses, TPD or TPR for broilers and turkeys in the current study. The ratio of phytate P to total P in the wheat-DDGS used in the current study was 0.23 and this value is similar to the average of 7 samples (0.27) reported by Noblet et al. (2012). Compared with wheat, the phytate P level in the wheat-DDGS used in the current study was lower than the mean of 22 wheat samples (0.15% vs. 0.25%, respectively) analyzed in Noblet et al. (2012) study. At the inclusion rate of 200, 400 or 600

g/kg, the diets used in the current study contained 0.3 g/kg, 0.6 g/kg or 1.0 g/kg of phytate-P, respectively which may not have provided sufficient level of substrate for the supplemental phytase to cause significant improvement in P digestibility. The low level of phytate bound P in the wheat-DDGS used in the current study corroborates the high TPD and TPR noted for broilers and turkeys and may explain the lack of phytase effect.

5. Conclusions

In conclusion, the results from the current study show that wheat-DDGS is an exceptional source of digestible and retainable P for broilers and turkeys; thus the inclusion of wheat-DDGS in the diet will reduce the use of inorganic P sources. Supplemental phytase had no effect on ileal P digestibility or total tract P retention of the wheat-DDGS for broilers and turkeys most likely because the wheat-DDGS contained low levels of phytate-bound P.

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337 **Table 1**

338 Analyzed nutrient composition of wheat distillers dried grains with solubles (as-is basis)

Item	g/kg
Dry matter	858
Crude protein	326
Gross energy (MJ/kg)	18.5
Crude fibre	80.0
Ether extract	72.5
Neutral detergent fibre	389
Acid detergent fibre	223
Ash	46.0
Ca	1.60
Total P	6.50
Phytate P	1.50
K	10.6
Na	4.80
Mg	2.2
Fe	0.40
Mn	0.06
Cu	0.01
Zn	0.06
Amino acids	
Arg	11.8
His	8.30
Ile	13.7
Leu	22.6
Lys	7.70
Phe	15.8
Thr	11.5
Met	4.50
Trp	3.80
Val	16.2

Table 2

Ingredient and chemical composition of experimental diets to determine the phosphorus digestibility and retention in wheat distillers dried grains with solubles for broilers and turkeys.

	Wheat distillers dried grains with solubles inclusion level, g/kg		
Item	200	400	600
Ingredients, g/kg			
Maize starch[1]	516	293.5	77
Wheat-DDGS	200	400	600
Soybean oil	18	36	48
Dextrose	100	100	100
Sucrose	130	130	130
Vitamin-mineral premix[2]	2.5	2.5	2.5
Limestone	4.5	9	13.5
Common salt	4	4	4
Marker premix[3]	15	15	15
Phytase premix	10	10	10
Analyzed composition[4]			
Dry matter, g/kg	880	890	885
Phosphorus, g/kg	2.0	2.9	4.2
Calcium, g/kg	3.5	4.7	6.9
Phytase activity, FTU/kg	962	810	933

[1]Phytase premix replaced maize-starch at 10 g/kg.

[2]Vitamin and mineral premix supplied per kg of diet: Vitamin A, 16,000 IU; vitamin D3, 3,000 IU; vitamin E, 25 IU; vitamin B1, 3 mg; vitamin B2, 10 mg; vitamin B6, 3 mg; vitamin B12, 15 µg; nicotinic acid, 60 mg; pantothenic acid, 14.7 mg; folic acid, 1.5 mg; Biotin, 125 µg; choline chloride, 25 mg; iron, 20 mg; copper, 10 mg; manganese, 100 mg; cobalt, 1.0 mg; zinc, 82.2 mg; iodine, 1 mg; selenium, 0.2 mg; and molybdenum, 0.5 mg.

[3]Contained 1 g of titanium dioxide added to 4 g of maize-starch.

[4]Values are means of duplicate analyses

Table 3

Ileal digestibility and total tract retention coefficients of dietary dry matter and phosphorus for broilers and turkeys receiving graded levels of wheat distillers dried grains with solubles with or without phytase supplementation[1].

	Broilers				Turkeys			
Measurements	Ileal DM digestibility	Total tract DM retention	Ileal P digestibility	Total tract P retention	Ileal DM digestibility	Total tract DM retention	Ileal P digestibility	Total tract P retention
Wheat-DDGS effect								
200 g/kg of wDDGS	0.79	0.79	0.63	0.60	0.75	0.75	0.45	0.19
400 g/kg of wDDGS	0.71	0.73	0.57	0.54	0.61	0.68	0.38	0.25
600 g/kg of wDDGS	0.65	0.68	0.61	0.46	0.51	0.61	0.35	0.20
S.E	0.02	0.01	0.03	0.04	0.02	0.01	0.05	0.05
P values for main effect of wDDGS levels	<0.001	<0.001	0.154	0.011	<0.001	<0.001	0.181	0.442
Phytase effect								
Without phytase	0.73	0.74	0.60	0.55	0.61	0.67	0.35	0.19
With phytase	0.70	0.73	0.61	0.52	0.64	0.69	0.43	0.24
S.E	0.01	0.08	0.03	0.04	0.02	0.01	0.04	0.04
P values for main effects of phytase	0.068	0.110	0.609	0.511	0.137	0.104	0.078	0.257
wDDGS × phytase interaction	0.969	0.660	0.493	0.574	0.865	0.917	0.346	0.474
P values for effect of wDDGS inclusion								
DDGS (linear)	<0.001	<0.001	0.392	0.003	<0.001	<0.001	0.072	0.860
DDGS (quadratic)	0.299	0.676	0.082	0.708	0.344	0.672	0.697	0.209

[1]Data are means of 7 replicate pens

DM – dry matter; s.e.d - standard error of difference of mean; wDDGS – wheat distillers dried grains with solubles

Table 4

True ileal phosphorus digestibility and true phosphorus retention of wheat distillers dried grains with solubles without or with phytase supplementation for broilers and turkeys[1].

	Regression equation[2]	r^2	SE of slope[3]	TPD coefficient[4]	TPR coefficient[4]	DP[5], g/kg	RP[5], g/kg
Experiment 1 - broilers							
True ileal P digestibility							
Without phytase	Y= 0.064X - 476	0.661	0.010	0.94	-	6.0	-
With phytase	Y = 0.040X + 174	0.725	0.005	0.96	-	6.2	-
True total tract P retention							
Without phytase	Y = 0.063X - 625	0.534	0.016	-	0.92	-	6.0
With phytase	Y = 0.065X - 201	0.689	0.010	-	0.94	-	6.1
Experiment 2 - turkeys							
True ileal P digestibility							
Without phytase	Y = 0.242X - 430	0.650	0.039	0.76	-	4.9	-
With phytase	Y = 0.179X - 98	0.422	0.047	0.82	-	5.3	-
True total tract P retention							
Without phytase	Y = 0.294X - 293	0.612	0.056	-	0.71	-	4.6
With phytase	Y = 0.184X + 451	0.375	0.054	-	0.82	-	5.3

[1]Data are means of 7 replicate pens

[2]Ileal or excreta P output (mg/kg of DM intake) regressed against dietary P intake (mg/kg of DM). The intercept of the regression term is endogenous P loss (mg/kg of DM intake) whereas the slope is true P indigestibility.

[3]Standard error of regression components

[4]Calculated as 1 - true P indigestibility; TPD or TPR are coefficients of true ileal P digestibility or true P retention, respectively. Phytase had no effect on TPD and TPR of the wheat-DDGS.

[5]DP and RP are digestible P and retainable P contents of wheat-DDGS, respectively. Calculated as coefficients of true P digestibility or retention multiplied by analyzed P content in wheat-DDGS (g/kg).